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SPECIAL ARTCILE

Minimizing the aerosol-generating procedures in Orthodontics in the era of a pandemic: current evidence and guidelines to reduce hazardous effects for the treatment team and patients

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Abstract

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Minimization of water- spray syringe utilization for rinsing is suggested on bonding related procedures, while temporal conditions as represented by seasonal epidemics should be considered for the decision of intervention scheme provided as a pre- procedural mouthrinse, in an attempt to reduce the load of aerosolized pathogens. In normal conditions, chlorhexidine 0.2%, preferably under elevated temperature state should be prioritized bacterial counts. In the presence of oxidation vulnerable viruses within the community, substitute strategies might be represented by the use of povidone iodine 0.2- 1%, or hydrogen peroxide 1%. Following debonding, extensive material grinding, as well as aligner related attachment clean- up, should involve the use of carbide tungsten burs under water cooling conditions for cutting efficiency enhancement, duration restriction of the procedure, as well as reduction of aerosolized nanoparticles. In this respect, selection strategies of malocclusions eligible for aligner treatment should be reconsidered and future perspectives may entail careful and more restricted utilization of attachment grips. For more limited clean- up procedures, such as grinding of minimal amounts of adhesive remnants, or individualized bracket debonding in the course of treatment, hand- instruments for remnant removal might well represent an effective strategy. Efforts to minimize the use of rotary instrumentation in orthodontic settings might also lead the way for future solutions.

Measures of self- protection for the treatment team should never be neglected. Dressing gowns and facemasks with filter protection layers, appropriate ventilation and fresh air flow within the operating room comprise significant links to the overall picture of practice management. Risk management considerations should be constant, but also updated as new material applications come into play, while being grounded on the best available evidence.

Introduction

The pandemic outbreak of SARS-CoV-2 has attained large impact to the frontline of healthcare workers, and amongst those to dentists and orthodontists[1]. Leaving aside, in theoretical grounds, the public health and the economic burden of the covid-19 disease, it is now evident that its massive spread around the world has imposed great occupational challenges, with implementation of routine dental services being at stake[2]. The nature of the virus' infectious route, with direct implication of airborne droplets[3] in the form of aerosol, has revealed certain potential hazards underlying conventional and standard oral health care procedures. Orthodontic practices are not to be left aside. An aerosol is defined as a suspension system of solid or liquid particles in a gas[4]. The term was introduced by Frederick G. Donnan to describe an aero-solution, clouds of microscopic particles in air. Various types of aerosol, classified according to physical form and how they were generated, include dust, fume, mist, smoke and fog. Aerosol should be differentiated from solid particles staying airborne for some time in the air, and splatter of relatively large sized droplets of water generated by splashes in a dental setting such as those produced by using the water syringe.

Aerosol producing dental procedures along with upcoming concerns are not new to the dental discipline and utmost, these concerns should not be selectively twisted, hampered or emphasized under the light of the present pandemic or potentially future endemics to come. They are effectively there since more than 20 years, and protective measures for dentists and clinic personnel should be prioritized in practice, irrespective of the presence of a pandemic, epidemic, normalized conditions or otherwise[5]. On top, these concerns and protective measures should effectively be carried forward through advancements in technologies, as well as evidence directed by new knowledge, over the years. It is just that the current pandemic situation has boosted our thinking and endorsements on how to efficiently manage and minimize aerosol production in contemporary practice.

Apparently, common categories and burden of orthodontic related applications producing aerosol and/ or airborne particulates are focusing on bonding and debonding strategies. The former involve application of water- spray practices in connection to enamel etching, prior to conditioning with bonding agents and bracket bonding; the latter pertain to enamel clean- up practices after removal of fixed appliances upon completion of orthodontic treatment. In the same line of debonding strategies, an additional procedure liable to aerosol generation has lately emerged in the clinical field; composite attachment removal after aligner therapy or possible attachment replacement/ removal cycles during treatment with aligners is not to be neglected[6,7]. This is particularly striking if one considers that the majority of orthodontists and/ or other clinicians utilizing aligner methods to straighten teeth and treat malocclusions have adopted wide application of these adjuncts in everyday practice[8,9].

With regard to bonding strategies, conventional acid etching stage may be employed with the use of a gel etchant of very thick consistency, a gel of lower viscosity, or a liquid etchant (Figure 1). Implications for the first alternative are rather straightforward as it might require a considerably higher water pressure flow to be rinsed off, also a longer rinsing period, but practically there is more. Very thick consistencies of gel essentially negate the action of acid for the amount of material not in contact with the enamel surface due to limited wetting, thus the other two alternatives are often selected. The higher water pressure used however generates splatter, which does not belong to the aerosol classification, nonetheless, may too contribute to the contamination of the operatory. Water pressure is normally set at 40 PSI in the dental units, with existing air pressure at 80 PSI. The American Dental Association (ADA) has suggested testing of water squirt of more than 1.3 meters (~ 4 feet), as a practical measure of raised water pressure[10].

Regarding debonding strategies of fixed appliances, implication of rotary instruments used to remove remnants of composite compounds after fixed appliance removal, as well as utilization of water as cooling agent during handpiece usage form priority factors should be considered. Cutting efficiency and aerosolized dust formation are also discussed.

The aim of the present narrative article is to discuss the hazards arising from routine orthodontic practices implicated to aerosol generation, sometimes on par with, and following examples from standard dental procedures, and also to elucidate potential interventions or alterations of conventional orthodontic applications as an attempt to minimize substantial hazards or adverse effects. The narrative is built on two basic pillars regarding aerosol generation; the microbiologic on one side, and particulate production and toxicity related implications on the other.

Microbiologic considerations and bio-aerosols

The pathogenic pervasiveness of dental aerosol rests in its dependence on the concentration of bacterium or virus load in compressed air, or water- spray spatter mixed- up with tooth material, plaque, blood, calculus and saliva debris that are theoretically and practically produced during routine dental practice, which makes use of an intraoral service handpiece; as such, orthodontic practices fall within the range of these procedures, apparently within a more limited extent, but importantly not to be neglected. The presence of dental unit waterlines (DUWLs) microbiota has also been considered an additional intriguing factor, especially as pathogens are being carried forward through the water supply system directly to the handpiece in use[11]. When use of coolants during service is taking place, the interaction of the cooling agent, with fluids and debris produced within the oral environment as a result of composite or tooth grinding practices or use of ultrasonic scaling is present and inductively it may be detected in air- suspended particles and aerosol[11]. The Centers of Disease Control and Prevention[12] (CDC) has established a safety maximum level of colony forming units (CFUs) emitted and detected in the air, as a result of dental handpiece and water/ air supply instrumentation usage, at the threshold of 500 per ml, excluding coliform bacteria for non- surgical procedures. These levels are liable to reduction when immunocompromised patients are in chair, being lowered to 200 CFUs per ml. Evaluation of pathogen levels may be done through simple commercially available test strips or kits. Alongside, dental air/ water related instrumentation (handpiece/ spary syringe/ ultrasonic scaler) in direct usage to patients' oral cavity should be flushed and pseudo- tested for 2 minutes each starting day, while also for 30 seconds between patients[13].

A recent systematic review on bioaerosols in dental environment has pinpointed the presence of 38 types of micro- organisms, including 19 bacteria and 23 fungal genera, indicating a high variety of a range of species, whereas it was interesting that none of the included articles reported on the presence of viruses or parasites; apparently, this is not linked to their absence from air suspended droplets, but rather to line of focus of the primary studies, partially in favor of the abundance and commonness of the former pathogens and their easier and non-specific detection through wide air sampling techniques[14]. A mean bacterial load range of 1 to 3.9 CFUs in logarithmic scale has been reported after procedural produced aerosol, while the most eminent load has been reported in the range of 1.5 meters from the oral cavity, even higher compared to closer distance measures such as that of one meter from the patient[15]. *Fusobacterium* family pathogens have been identified in aerosols produced after ultrasonic scaling in practice through checkerboard DNA- DNA hybridization techniques[16,17]. Of the family, *Fusobacterium nucleatum* has been identified as a bacterium related to pathologic ophthalmic and respiratory implications, while also inductive of cellular apoptosis in vivo[18,19]. In addition, it has been reported as related to the launch and progression of periodontitis, or as attenuating attribute of gingival fibroblast mesenchymal cell proliferation[20]. However, the results of checkerboard hybridization techniques should be interpreted with caution as per the exact bacteria species eligible for identification, since such practices are close ended, checked in pre- selected DNA- probe panels and other pathogens not pre- specified might as well be present within droplet spatters. Nonetheless, studies assessing mostly periodontal pathogens have identified an increased prevalence of species belonging to the so- called “orange complex” in aerosols generated during usage of ultrasonic scaler[16,17]. These mostly pertained to *Campylobacter rectus*, *Prevotella Intermedia* and others, including *Fusobacterium periodonticum* in addition to *Fusobacterium nucleatum*. Apart from directly exposed aerosolized bacteria, another potential contamination source within dental offices or in hospital based dental units has been identified and special attention has been placed to the presence of *Legionella pneumophilla* as well as *Pseudomonas spp* in DUWLs[11,21]. These, might well serve as routes of infection for patients and/ or dental personnel indirectly and via droplet suspension after aerosol generating handpiece or water/ spray syringe usage. Other sources of *Legionella pneumophilla* constitute air- conditioning systems or cooling towers within dental settings[14,22]. Interestingly, the novel SARS-CoV-2 has also been lately reported to demonstrate capacity of emanation via the airflow of air-conditioning units in business environments[23].

An array of clinical studies, since more than 25 years and until recently, have attempted to identify effective methods of reducing pathogen load stemming from aerosol forming procedures in dental settings (Figure 2). The vast majority have studied in- service utilization of ultrasonic scaling[17,24–30], while some have reported on orthodontic related strategies of debonding procedures[31,32], or other dental prophylaxis or restorative procedures[33,34]. Largescale efforts have been lately endorsed to collectively appraise all available evidence and provide justifiable ranking of the efficiency of these methods[35,36]. The most prevalent recorded approaches were preprocedural mouthrinse using a wide variety of potentially antimicrobial agents, such as, chlorhexidine (CHX) 0.12%, CHX 0.2% or tempered CHX 0.2%, cetylpiridinium chloride (CPC) 0.05%, povidone iodine (PI) 1%, chlorine dioxide (ClO_2), herbal- based agents, or others pertaining to ozone irrigation, use of high volume evacuators/ dental isolation systems, or agents added to DUWLs to reduce the load[27,28,37,38].

Evidence from a study on bacterial load during orthodontic procedures comparing bracket debonding followed by enamel clean up with high- speed handpiece and water cooling versus standard orthodontic care involving archwire/ ligature change and replacing procedures, highlighted the increased pathogenic state of aerosols produced by the former, with a mean difference of 49.2 (95% CI: 19.4, 79.0) in total CFUs[31]. This highlights the exposure hazards of orthodontists related to certain orthodontic procedures in practice and draws attention to additional prophylactic measures to be selectively taken within the dental operating office. Effectively, bacterial load in aerosol in the dental/ orthodontic cabinet has shown to be significantly raised immediately within 5 minutes of service for an aerosol generating procedure, including enamel clean- up.

Further evidence on microbiologic assessment of aerosol produced after debonding of fixed orthodontic appliances and during composite clean- up has elucidated the increased potential of aerosolized particles, particularly those with aerodynamic diameters of 50μm or less[39], to surpass the respiratory barriers and invade deep into the lungs[32], along with pathogen contaminants. Bioaerosol infiltration has been detected in simulation studies all the way to the respiratory tree from the pharynx to the bronchial alveoli of the lungs. Although decreased particulate size seems to exhibit increased potential to penetrate deep into the lungs, the viability of pathogens has been shown to simultaneously decrease, impacting also biodiversity at the deep respiratory levels[32,40].

Use of preprocedural mouthrinse with CHX of either 0.12 or 0.2% concentration has been identified by individual studies as an important de- contaminating agent contributing to identification of decreased bacterial amounts of infected aerosol[29,30,41]; latest data coming from an endorsement to compare all direct and indirect evidence from examined interventions (mouthrinses, evacuators, decontamination of DUWLs and others) across studies and within dental settings, has revealed this supremacy of preprocedural chlorhexidine mouthrinse over other measures for 30 seconds to 1 minute, but also with documented prevailing of tempered (47^{o} C) CHX 0.2%[27,35,36,42]. Tempered CHX solution at 47^{o} C, has been reported to offer increased anti-microbiologic action against bacteria of the human dental plaque, while also preserving adverse effects on tooth and pulp vitality to the minimum[43]. The increase in bacterial kill rate has been determined to reach as high as 25% surplus, while to avoid storage contamination with toxic compounds such as p- chloroaniline, freshly made CHX solutions should undergo heating[43]. As this measure might be potentially considered impractical for the routine management of clinical practice, it might still be the treatment of choice for highly prone to aerosol induction procedures, with water cooling involvement; other solutions could also be considered for more conservative procedures. Amongst the first priority treatments of choice and apart from CHX solutions (either tempered or non- tempered), povidone iodine 1% has also been considered a viable alternative[35,36].

Aforementioned documented evidence originates, as discussed, primarily from ultrasonic scaling clinical studies, randomized in most cases, while total bacterial count in generated aerosol has been the outcome of interest, leaving virus load aside. Extrapolation to other potentially producing aerosolized compounds procedures, however, seems reasonable within a dental cabinet setting and certain orthodontic procedures, such as fixed appliance debonding, may benefit from such measures.

At present and in the middle of SARS-CoV-2 pandemic mid- 2020, there is no evidence from clinical trials on the effectiveness of interventions taken pre- procedurally in dental offices against viral load in air- suspended droplets or aerosols. However, it would be reasonable to assume that mouthrinses or irrigates with proven capacity to interact with viral molecules and its cellular membranes might prove beneficial. Based on the oxidative action of such agents against the lipid membrane of coronaviruses, latest reports[44,45] as well as primary guidelines of the National Health Commission by the People's Republic of China[46], on measures against SARS-CoV-2, have indicated a decreased effectiveness of chlorhexidine as a measure of choice, mostly because of the lack of oxidative action, while use of hydrogen peroxide (H_2O_2) 1%, or povidone iodine (PI) 0.2% to 1% appear more realistic as effective alternatives. Oxidative agents act directly on the lipid shell membrane of the virus and destroy cellular components. In particular, PI action is enhanced by the slow and gradual release of iodine as carried by povidone vehicle, while any adverse effects of iodine are reduced allowing for a toxicity- free simultaneous interaction[47]. Based on the absence of clinical trials in the field of virus load of aerosols, latest calls have emerged and suggest the use of flavonoids or cyclodextrine agents to fight or attenuate SARS-CoV-2 infection through saliva expectorations or spatters secretions[48]. However, their effectiveness remains to be tested.

Composite grinding and particulate production

Cutting instrumentation

Composite grinding and particulate production during handpiece instrumentation usage in routine dental practice has been considered an additional source of potentially hazardous concern for dentists and orthodontists in general, but also in particular in the middle of a pandemic of a novel severe acute respiratory syndrome–coronavirus- 2 (SARS-CoV-2), with unprecedented impact worldwide[1].

An initial notion prior to any consideration of produced aerosolized dust is cutting efficiency and types of dental rotary instruments that might effectively reduce grinding duration. Knowledge on the topic may largely be attributed to the extensive research and work on this field by A.J. von Fraunhofer and collaborators[49–53].

Type of cutting bur and mode of action

First, discrimination between commonly used burs in terms of cutting mechanism is discussed, roughly between two of the most prevalent cutting instruments in use, tungsten carbide and diamond burs. The tungsten carbide burs differ from diamond burs, as they are considered to achieve material removal through a flow- dependent fracture process (plastic flow), occurring as a result of elevated shear forces between the carbide blades and the material surface; this makes them rotary instruments of choice for cutting ductile substrates including composites, dentin or metals. Dissimilarly, diamond cutting burs induce brittle fracture of substrates, functioning by creating grooves and making use of dislocation motion and subsequent radial flow of the material, ultimately leading to propagation of cracks by the generated tensile stresses produced and chip formation. Apparently, diamond burs are mostly efficient for ceramics or enamel surface[49]. Latest innovations for adhesive removal after completion of orthodontic treatment, entail the use of fiber- glass or fiber- reinforced composite burs, which have been reported to exhibit a potential for reduced enamel surface roughness on enamel clean- up, compared to standard carbides[54,55]. However, no data is currently available with respect to the effect of these cutting burs on particulate composite dust dynamic.

Moreover, water supplementation and spray patterns of the handpiece during tooth or material grinding, apart from the straightforward effect on preservation of temperature within tooth teeth and pulpal tolerable standards[56], have also been implicated as a medium for achieving efficiency during the cutting procedure. Water spray during tooth preparation within a proximal value of 40-ml/min room temperature has been considered reasonable for avoiding pulp interactions[56]. In reality, water or other lubrication medium has been considered to play a significant role in cutting efficiency following Reynold's hydrodynamic lubrication theory.

In particular, across dental setting environments where standard and known length and material cutting instruments are used for commonly used 400,000 rpm bur rotation speed, it appears unlikely that effects of dynamic viscosity of coolant media may be significant. Testing across water coolant, alcohol (1%) as well as glycerol (2%) solution has revealed comparable effects[49].

Further, water application as coolant usage during material grinding in practice, including enamel clean- up from bonding remnants after orthodontic treatment, offer a thin line layer of interproximal matter between the carbide and material interface. This is considered to induce surface adsorption alterations in the substrate material following reduction of the surface- free energy, produced by changes in the strength of association of the interatomic bounds between interactive entities, thus resulting to surface hardness changes[49]. To this respect, and as discussed above, cutting with carbide burs in ductile substrates such as resin remnants after debonding of fixed appliances or bonded attachment removal after or during aligner therapy, shall be advantaged, in terms of cutting efficiency, by water supplementation targeted directly to the carbide- composite interface, in the following manner: initial groove formation after bur application is generated, followed by lateral displacement of the substrate, pilling- up material dislocation and crack propagation, resulting in chip formation[49]. The described procedure broadly follows the original work of Rehbinder and colleagues back in 1940's, who suggested that chemically- induced surface hardness changes bear the potential to increase drilling efficiency of the cutting tool in mining settings with aqueous surfactant solutions, within a range of 30- 50% [57]. Gain is two- fold, with subsequent extrapolation to orthodontic and dental practice: faster advancement of the bur into the substrate and decreased demand for heavy load application in practice, thus reduction in operating time and total amount of aerosol production.

Material substrate, composite dust and aerosol

Resin composites are known to possess a wide range of applications in dentistry[58], with orthodontics usage in bonding procedures of both fixed appliances as well as treatment with aligners and attachment adjuncts being in the spotlight. Normal composite composition comprises of the resin matrix [usually represented by BisGMA, bisphenol A diglycidyl dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; BisEMA, ethoxylated bisphenol A glycol dimethacrylate], the inorganic filler compounds as well as a coupling agent to guarantee bonding between the two[59–63]. Filler compounds usually fall below 0.4 μm and may serve in a wide range of particulate sizes and even fall within the nano- range[62,63]. Orthodontic adhesives have also been considered to acquire quartz- type filler particles as well[64]. Heavy metal oxides are preferred, namely barium, strontium, zinc, aluminum or zirconium[65], while their primary service remains to offer enhanced physical and mechanical properties to the material, including polymerization shrinkage water sorption and solubility, radiopacity, reduction of biodegradation in- service[66–68].

During debonding strategies, but also lately increasingly during attachment removal in the course of/ after the end of aligner treatment with thermoplastic- type devices, breakdown of the bulk of composites takes place, with material micro-/ nano- fragments being aerosolized[6]. These particulates bear the aerodynamic potential to surpass the respiratory fraction barriers and natural defense mechanisms of the clinician, patient and office personnel and find their way deep into the lungs[69,70].

A foremost effort to provide evidence in the field of aerosolized composite compounds in dental settings, has been mainly initiated and driven by two separately working groups in Leuven, Belgium[64,70–74] and Bristol in the United Kingdom[32,69,75], in essence following simulation in clinical conditions. Apparently, aerosols comprising of particles lower than 10μm or 2.5μm (PM_{10} or $PM_{2.5}$, particulate matter) are gaining attention due to their potential to enter the respiratory tract[76–78]; interestingly, even smaller particulates within the range of dozens of nanometers (<100nm) have been associated with an increased dynamic to surpass the primary boundaries of the respiratory system and reach deepest levels of the terminal epithelial bronchioles of the lungs, due to their increased surface to volume ratio, offering an amplified reactive potential when in interaction with cellular interfaces[79–82].

Several studies have investigated the content compounds of composite dust produced in aerosols in dental and orthodontic setting[64,70,71,73], while it has been claimed that percentage and concentration of nano- sized identified filler particles in the aerosols might be related to the original filler content of the composites; however this is far from the case, since all types of composites, irrespective of filler size, have been reported to exhibit significant amounts of nanoparticles, within the range of 38- 70nm during grinding and cleanup[71]. In particular, surface friction and heating shock during composite grinding results to matrix decomposition of the substrate, aging, C=C conversion of bonds on surface and ultimately production of respirable composite dust[83–85].

Wet or dry conditions

Apart from water supplementation contribution to the cutting efficiency of grinding tools upon the composite substrate during debonding, thus offering minimization of (bio)- aerosol production duration, the effect of water as per emanation and generation of airborne dust has been disputed, however, with scarce evidence from few research efforts, across variable settings. In essence, a recent study[74] inspected the effect of water cooling in slow- handpiece usage on bulk composite sticks containing an array of filler sizes under simulated conditions of dry and wet grinding. Their work suggested consistent findings for all types of composites, which demonstrated a significant reduction in the number of detected nanoparticles being released when water spray was in- service ($5.6*10^5$- $13.7*10^5$ in #/ cm^3), denoting a half- pace reduction, compared to dry settings. Interestingly though, both dry and wet grinding alternatives produced high numbers of nano- sized particulates being aerosolized overall. The highest amounts have been detected during the last minute of grinding, reaching levels of approximately $33*10^5$ numbers/ cm^3. Particulate agglomeration has been considered to occur across time, thus contributing in increasing average particulate diameter overall. To this respect, under water usage conditions, airborne generated nanoparticles have been considered particularly prone to being trapped within water droplets, resulting in increased matter sizes, which are less likely to achieve penetration of the epithelial bronchial barriers and find their way to the lungs.

The aforementioned conditions and settings could be considered as vastly resembling to the bulk attachment material removal during orthodontic treatment with aligners[6]. As previously discussed, aligner usage for treatment of malocclusions currently involves increasingly frequent adoption of composite grips bonded to tooth enamel, sometimes more than 1 per tooth, as attachments of various sizes and shapes[6,8], with non- negligible dimensions, varying within the range of 2- 5 mm and also width or thickness that may exceed 1 mm. These adjuncts target to the achievement of modes of tooth movement, either rotational or translational, within all three planes of space, which would otherwise be non- manageable with the early phase plain thermoplastic aligner usage, which do not necessitate enamel involvement[86]. This compares to the thin layer of composites used as a layer of “sandwich-type” pattern between the bracket base and the enamel surface in a conventional case fixed appliance treatment[87], with an average estimated thickness of 150 to 250 μm; one may evidently cognize that the bulk and thickness of the attachment grips in aligner therapy is implicated in two conditions: first, the occurrence of an excessive amount of composite polymerized material within the oral cavity, allowing for the potential risk of bisphenol- A (BPA) release or monomer leaching, depending on the number and shape or size[6,59,88]; second, grinding procedures for attachment removal may prove extremely exhaustive and timely, bearing an increasing risk of excessive production of aerosolized composite dust[6].

Handpiece role

Furthermore, an earlier report on human extracted teeth and subsequent simulated bracket removal and enamel clean- up, has examined the effect of handpiece, water coolant, high volume evacuateor (HVE) as well as surgical facemask, on the amount of particulate production and particle concentration during composite grinding following debonding[75]; however, the baseline effect of handpiece was variable, since slow- speed handpiece was utilized in absence of water coolant, whereas high- speed handpiece only under water spray emission. Findings, structured on non- parametric data, revealed a significantly higher concentration of airborne particulates under wet conditions and the use of high- speed instrumentation. Also, use of facemask appeared considerably effective, contributing to the reduction of the detected concentration, while HVE was not identified as a critical parameter in this respect. To date, there is no further evidence on the direct crude effect of handpiece variation and rotary instrumentation speed with regard to airborne particulate generation, under otherwise comparable conditions.

Cytotoxicity and Estrogenicity of aerosolized particulates

Following research about cytotoxicity and xenoestrogenic effects of BPA/ monomer release of adhesive compounds within the oral cavity[88,89], airborne particulates produced during grinding of composites after fixed appliance removal or aligner's attachment elimination, are apparently a potential source of similar concerns. A mild but gradual reduction of human bronchial epithelial cell viability in laboratory conditions has been documented, giving rise to speculations on the reactive dynamic of such particulates[62–64,72]. Composite filler particles and matrix composition of restorative adhesives did not appear to play a role. Interestingly, the latest report encompassing orthodontic adhesive material evaluation at grinding stages after simulated conventional orthodontic treatment, pinpointed the aptitude of aerosolized particles of adhesives comprising of quartz- type fillers to demonstrate disrupting effects on interacting cell membrane integrity and cellular viability, while also to intervene with cellular growth potential of epithelial bronchial populations at an early stage[64]. These effects are probably related to the size and shape of such fillers' configuration, following the increased surface to volume ratio they present.

Related evidence on orthodontic adhesives comes also from the assessment of in- vitro estrogenicity of orthodontic composited ground under simulated bonding- debonding settings. Estrogenic effects appear as a result of residual monomer release (BPA), which follows action as an endocrine disruptor due to the very similar structure with beta- estradiol[59,90]. Under the use of highspeed handpiece without waterspray, eluents of airborne particulates after grinding different types of adhesives (ie, chemically or light- cured), have shown an increased proliferating capacity on MCF-7 breast cancer cells in- vitro[84].

Such findings are of particular interest and raise considerable awareness, when it comes to the large- scale removal of attachment grips implicated in aligner therapy. The bulkiness and volume of these adjuncts evidently requires a great amount of grinding efforts and intraoral cutting instrumentation service. It is therefore likely that a significant amount of heat influx occurs first at the surface of the composite substrate if not substantially cooled, resulting in heat- shock transmission to the matrix and material aging[84]. Resultant effects on chemical decomposition of the produced aerosolized dust with further implications on monomer release and Bis-GMA compounds might be alarming[91,92]. Thus, broad and time- consuming composite removal, as required in extensive removal of attachments, with no water cooling in- service, should largely be avoided, while further research in the field is critical to detect specific effects of water supplementation to the emanation of monomer, potentially estrogenic compounds.

Implications and recommendations for clinical practice

Direction of measures taken to minimize effects of aerosol production in orthodontic practice should target in two basic routes: *bonding* and *debonding* procedures, in essence those being interconnected (Table 1).

Bonding

The former basically comprises of procedures that take place prior to bracket placement on tooth surface and involve rinsing actions for enamel preparation agents, and use of certain types of bonding materials. As previously stated, very thick consistencies and substantial amounts of etchant acid gels applied on tooth surface, apart from presenting compromised action per se, apparently require higher water/ spray pressure to be rinsed off, thus increasing the likelihood for spatter emanation and droplet formation, but also resulting in prolonged working times. Conventional acid etching agents entailing low viscosity or even liquid gels should be prioritized. Self-etching primer alternatives have also been proposed[93,94], whilst these may require careful pumicing to ensure a precipitations- free enamel substrate. In the same line and to avoid rinsing application and aerosol production, glass- ionomer cements as compared to conventional light- cured counterparts may be preferred[95]. These material alternatives present a chemical interaction and adherence with enamel surface, do not involve prior conventional enamel conditioning, or involve a thin layer of polyacrylic acid agent in contact with enamel, with an induced shallow depth of penetration of approximately 5 to 7 μm[96]. They are also less susceptible to moisturized oral cavity conditions, thus offering a viable alternative to classic adhesives bringing the aforementioned advantages, but also bearing a reduced risk for iatrogenic damage to the enamel surface[97,98]. However, all currently and widely adopted bonding alternatives, do not target on the desirable minimization of adhesive remnants covering the enamel surface after debonding.

Starting from the necessity of an enamel- friendly bonding agent, there has been an endorsement and inspiration, following nature and wildlife environment, to design new material structures on par with living creatures' observations. These form the so- called "biomimetic" materials. For example, *gekkonidae* lizards (geckos) acquire a unique adhesion ability attributed to their foot pad, the "contact splitting"[99]. In particular, geckos' foot pad contains densely packed ultrafine hair, split in the endings, thus offering increased number of contact points per unit area, contributing to greater adhesion forces generated. As such, geckos are capable of sustaining their weight upside- down, with a gravity defying ability, without mediation of any chemical agent, relying only to physical forces, otherwise being impossible to achieve. This type of strong gecko- feet grip has inspired the design of medical adhesives and might attain applicability in orthodontic bonding agents for dry environments[100]. Moreover, to overcome failures of geckos' inspired materials, in wet conditions, scientists have studied the use of mussel adhesion as a combination approach, with a resulting new material named "geckel", which might exhibit enhanced adhesion potential both in dry and wet conditions. Mussel biomimetic polymers are based on L-3, 4-dihydroxyphenylalanine (DOPA), offering "sticky" and "glue" resembling properties in the materials[101]. In essence, biomimetic based bonding primers such as L- DOPA might offer clinicians a significant tool against oral environment conditions. In combination with geckos' related properties and applicability to bracket bases, sufficient bond strength to enamel surface might be achieved, without necessitation for prior enamel conditioning, also making debonding practices and enamel cleanup at the end of treatment, effortless.

Debonding

As pertains to debonding procedures, calls and endorsements for aerosol containment in general, should be focused firstly on preventive measures to minimize composite remnants after bracket removal in conventional orthodontics and secondly on effective grinding patterns to reduce dust, particulate generation and operating time, with further speculations on bio- aerosol formation and microbiologic perspectives, as well as xenoestrogenic action of the produced particulate matter. The composite- bracket base interface may play a significant role in achieving a desirable limited amount of adhesive remnant for grinding. Alterations in the adhesive- base interlocking characteristics may take place by induced modifications in the resin filler content and also in the adhesive retention patterns within the bracket base[96]. Targeting an efficient combination of bracket base mesh, size and shape with adhesive composition that may result in a cohesive composite fracture upon debonding, would allow for minimal enamel clean up (Figure 3).

In this respect, applications from high technology and automotive industries might offer reformative solutions in orthodontic procedures in the near future. Command- debond adhesives have lately been used in interlocking joint positions in technology adjuncts, to allow for a temperature controlled initiation of the debonding process[96,102]. This is achieved mostly through the embedding of thermally expandable particles (TEMs) into the adhesive matrix[103]. The idea about TEMs dates many decades back[104] and resides in the transformation of the particles through heat shock, occurring by softening of the cell particulate matter jointly with gasification of the inner liquid phase hydrocarbon[103]. In the same line, ferrous microparticles, within the micron range, have been introduced as fillers and act by being preferentially distributed- following external magnet polarity reversal, thus inducing destabilization of the polymer structure, initiating crack states within the resin matrix that may easily be diffused. Other initiatives might also entail application of irradiation to reverse polymerization and produce a highly viscuous adhesive state easily to be removed[96].

Wide adoption of BPA- free adhesives has been suggested for a range of dentistry applications including orthodontic bracket or fixed retainer bonding[105]. To this line, advantages of such alternatives which miss BPA monomer derivatives, have been directed towards the elimination of the reactive oxygen species produced after BPA leaching in the oral cavity, following incomplete polymerization of the adhesives and being able to incite an estrogenic potential. The majority of such alternatives make use of aliphatic co-monomers based on triethyleneglycol dimethacrylate, urethane dimethacrylate, cycloaliphatic dimethacrylates or are effectively represented by a single aromatic dimethacrylate derivative (PCDMA).These efforts might prove beneficial also with regard to elimination of BPA- release in aerosolized dust at the debonding stage[96,105].

Concluding Remarks

In all, wide and consistent adoption of occupational measures to control generation of aerosol in orthodontic practice should be universal, with microbiologic considerations, particulate matter production as well as toxicity related perspectives being on the spot, even more within the course of a pandemic. Realistic management in practice, should focus on bonding and debonding strategies, while careful selection of procedures and application of safety measures depending on individualized patient needs is fundamental.

In particular, minimization of water- spray syringe utilization for rinsing is anticipated on bonding related procedures, while temporal conditions as represented by seasonal epidemics should be considered for the decision of intervention scheme provided as a pre- procedural mouthrinse, in an attempt to reduce the load of aerosolized pathogens. In normal conditions, CHX 0.2%, preferably under elevated temperature state should be selected for minimization of bacterial load. In the presence and spread of oxidation vulnerable viruses within the community, substitute strategies should be opted, effectively represented by the use of PI 0.2- 1%, or H_2O_2 1%.

Following debonding, largescale enamel clean- up strategies should entail the use of carbide tungsten burs under water cooling conditions, to augment cutting efficiency, timely fulfillment of the procedure, as well as reduction of aerosolized nanoparticles. Attachment clean- up at the end of aligner therapy fall into this category; however, selection strategies of malocclusions eligible for aligner treatment should be reconsidered and a more confined use of attachment grips might also be a viable future perspective. For more limited clean- up procedures, with traces of adhesive remnants left on enamel substrate, or individual "re-bracketings" or grinding after bracket breakage in the course of treatment, water cooling rotary instrumentation might not be the treatment of choice, while hand- instruments for remnant removal might well represent an effective strategy.

On top of the above, in- office measures of self- protection should never be neglected. Dressing gowns and facemasks with filter protection layers and face shields for all clinic personnel, appropriate ventilation and fresh air flow within the operating room are of paramount importance. Risk management considerations should be constant, but also updated as new material applications come into practice and/ or epidemiologic equilibrium of the community is disrupted.

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FIGURE LEGENDS

Figure 1. Etching agents with variable viscosity. Note the considerably lower viscosity of the "green" agent, resembling a liquid etchant state, preferable for minimal water pressure flow to be rinsed off.

Figure 2. Network map geometry for competing interventions with regard to bacterial load reduction in produced aerosol within dental settings. Size of the node is analogous to the contribution of the sample size for each intervention overall and width of edge to the number of direct comparisons (HVE, high volume evacuator; CHX, chlorhexidine; CPC, cetylpiridinium chloride; OZ, ozone; PI, povidone iodine; HRB, herbal; ClO_2, chloride dioxide).

Figure 3. Tooth enamel and composite remnants after bracket debonding. A. cohesive resin fracture with reduced amounts of remnants. B. excessive composite remnants (bracket base mirror-mesh is evident).

TABLES

Table 1. Recommendations and safety measures to minimize aerosols in orthodontic practice, per procedure.

Procedure	Aerosol- liable actions (conventional)	Safety measures	Future perspectives
Etching	High thickness/ viscosity gel	Liquid gel/ low viscosity	Non- etching mediated bonding
		Self- etching primer/ no-rinsing	
		Glass- ionomer cement/ no-rinsing	
Bonding	Conventional resin- based adhesive	Glass ionomer cement	Biomimetic based bonding with use of L-DOPA primers
		BPA- free adhesives	
Debonding	Standard debonding with considerable amounts of adhesive remnants on enamel surface	Alteration of adhesive- bracket base interface	Command- debond adhesives (thermally expandable particles, ferrous micro-particles)
		Identify bracket base mesh/ shape/ size and adhesive combination for cohesive resin fracture	Irradiation of specific wavelength to reverse polymerization
			Biomimetic bonding agents would eliminate use of rotary instrumentation
	Standard rotary grinding to clean- up enamel	Removal of significant amounts of resin remnants with hand instruments- avoid rotary instrumentation as much as possible	Temperature control and variation of adhesives (heat/ freezing) - plasticization/ brittleness
		Use of tungsten burs* w/o water cooling for limited trace composite remnants (ie. individually debonded brackets during treatment)	
		Use of tungsten burs*, under water cooling for enamel clean- up after debonding/ attachment removal	
	Attachment grips for aligner treatment	Careful selection of patients/ malocclusions for treatment with aligners; abandon company pre- set distribution of arrays of attachments	
		Attachment- free aligner treatment	
		Use of BPA- free composite to eliminate estrogenic activity (ie, PCDMA)	
	Pre- procedural measures	Mouthrinse with (47°C) CHX 0.12- 0.2% for bacterial pathogens (0.5- 1 min)	
		Mouthrinse with 0.2- 1% PI or 1% H_2O_2 for oxidation vulnerable viruses (0.5- 1 min)	
	Personnel equipment/ settings	Facemask, shiled, gown; apparel for all clinic personnel; fresh air and surgical sunction	

*smaller number of flutes in the beginning or removal, advancing to 20- fluted for polishing; H_2O_2; hydrogen peroxide; L-DOPA, L-3, 4-dihydroxyphenylalanine; PCDMA, phenylcarbamoyloxy-propane dimethacrylate; PI, povidone iodine; w/o, without

FIGURES

Figure 1.

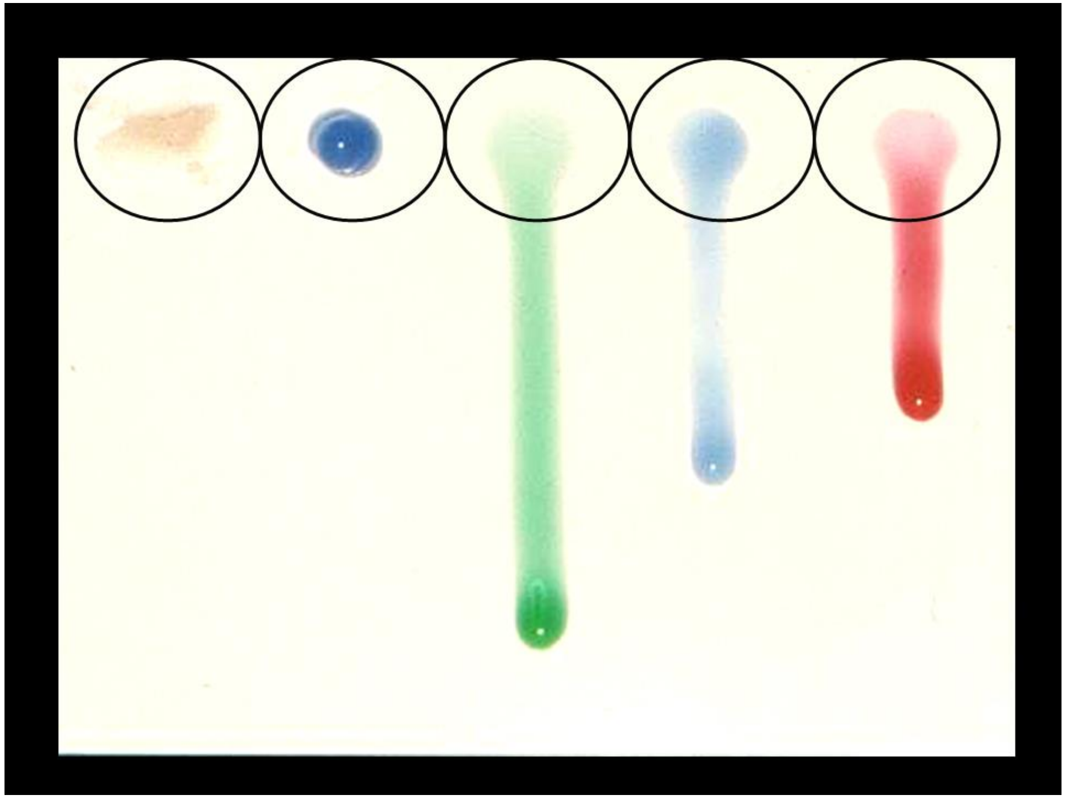

Figure 2.

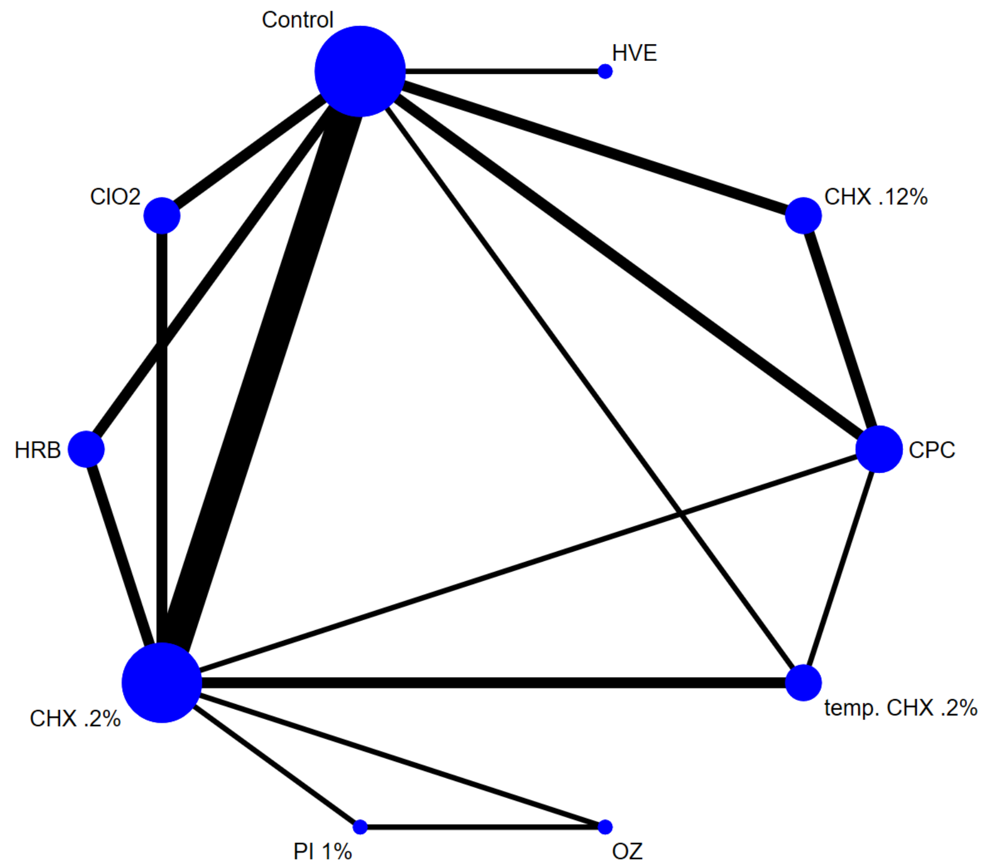

Figure 3A.

Figure 3B.